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where Ω is the observed surface rotation at any latitude, ω_0 is a constant derived from the calculations, and n is nearly equal to $2\frac{1}{4}$; taking $n = 2\frac{1}{4}$, ω_0 is about one half the equatorial value of Ω. The data being indeterminative, the observations are also consistent with the above expression supplemented by an infinite arbitrary series ; but it is shown that to attach a finite value to any term of this series implies that a finite part of the angular motion increases inwards at least as fast as r^{-2}, that is to say at much greater rate than the motion at the surface decreases towards the poles.

Finally it is shown that if the atmosphere follow the law of convective equilibrium, the associated surface motion in latitude is a slight drift towards the poles.

The Wilsonian Theory and the Stonyhurst Drawings of Sun Spots.

By the Rev. Walter Sidgreaves, S.J.

The question of the cavernous nature of a Sun spot has been recently brought prominently before the attention of Solar Physicists by the Rev. Mr. Howlett in a paper read at the last December meeting of the Royal Astronomical Society. His handsome present to the library of the Society is in evidence of the care and labour devoted to the subject, and the long series of large-size drawings contained in those eight volumes, covering a period of thirty-five years, seem to place his verdict against the Wilsonian theory beyond the reach of contradiction, and to show that it stands in no need of a confirming witness.

The Stonyhurst drawings extend over considerably less than half the years of Mr. Howlett's work, and are made to a scale, in diameter, only the one-third of his. They are therefore of much less weight, both in number and size. They were not commenced nor carried on with the direct object of testing the Wilsonian theory ; but this was never lost sight of, and occasionally, when a spot was near the limb, a special drawing was made of it from an enlarged image, after the usual full surface drawing of $10\frac{1}{2}$ inches diameter was complete. The smaller drawing of the spot on such occasions was never retouched after its examination under the greater magnification ; and the uniform agreement between the pairs confirms the rule that whatever is seen satisfactorily with less magnification is never contradicted by an enlarged image.

To form a safe estimate of the value of the smaller drawings for the subject of discussion, it should be remembered that in all cases the outlines of the umbra and penumbra were traced with a finely-pointed pencil over the image upon the paper, and that no drawing was considered complete until the draughtsman was satisfied that his picture faithfully represented what he saw. Hand-drawings made in this way have a value hardly inferior to

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that of a photograph, and may be even more trustworthy when not more than one photograph has been obtained.

For the selection of suitable spots over 2000 drawings have been examined dating from 1881 to 1894, and only those which were found to satisfy recognised conditions of suitability have received a mark for or against the Wilsonian theory. These conditions are :—(1) That the spot had been observed at a position approximately between 30 and 60′ of arc from either limb ; (2) that it had been watched on its passage between the central meridian and the limb ; (3) that it was a compact regular spot ; (4) that it showed a central umbra when remote from the limb ; and (5) that it was a quiet spot, not indicating a tendency to divide or to change shape. We have 146 spots fulfilling these conditions. Of these 41 were double observations, the spots having been followed from limb to limb and observed near each. We have therefore 187 single tests, and of these 140 stand against, and 47 in favour of Wilson's doctrine, making a statement of 3 : 1 against it. But the individual cases are not of equal value, and when weighted on an estimate of 4 to 1 between the best and poorest of the selected spots the proportion rises to 3·66 : 1 against Wilson. This, so far, is a much weaker opposition than is established by Mr. Howlett's more valuable collection of drawings. But if we estimate the worth of the 47 cases quoted for Wilson on the lines of his own valuation of their testimony, nearly all the 47 witnesses will go out of court. Dr. Wilson, in "An answer to the objections stated by M. de la Lande,"* that the Wilsonian foreshortening was not always seen, points out that a shallow spot must be much nearer the limb than a deep and steep one to exhibit the same inequality of the two sides of the penumbra, and that a very shallow spot would go off the limb without showing any perceptible difference of this nature. To make this clear he gives computed angular distances, from the limb, of four cavernous depths, at which the more foreshortened side would contract to a line, and appends the corresponding apparent widths of the opposite side. His figures for spots of the first and second classes, in the order of decreasing depths, are :—at 60″ from the limb, the inward side of penumbra vanishing and outer side width 8″·58 ; at 30″ distance, inward side vanishing, outer side width 6″ 02.† Now of our 47 cases favourable to Wilson the best is perhaps the one near the eastern limb on 1886 May 21. It is a good spot with a good history, and judging by its size and darkness it should be ranked at least in Wilson's second class. It should therefore, when at 30″ from the limb, have lost the inward side of its penumbra : it was just within 30″ distance, and showed the

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* *Phil. Trans.*, anno 1783, vol. lxxiii.

† The great spot of November 1769, which first drew Dr. Wilson's attention to the subject, was estimated, from his observations at the return of the spot in December, to have been at this limiting position, at 90″ from the eastern limb.

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inward side a little more than half the width of the outer side. It may well be doubted whether Dr. Wilson would have formulated his cavernous theory upon these cases, which would indicate declivities too small to be worthy of notice. There is, however, one case which has no exception to its evidence, and which but for the smallness of the spot would take precedence of the one just mentioned. It crossed the Sun's disc in the last half of July 1884. It appears on the drawings at 35″ from the eastern limb on the 17th, and at 2′ on the 18th, quite clearly for Wilson. On the 19th the umbra was central at 3′ 30″ distance. On the 20th the umbra was broken on the eastern side; but it had recovered on the 23rd, and remained quiet and central on the 24th and 25th. Finally, on the 28th, again at 35″ from the limb, it was the reversed picture of its first appearance. The diameter of the spot when near the middle of the disc on the 23rd was 20″, and it might be placed in Wilson's third class, which would not lose its inward penumbra at a distance greater than 15″.

In the course of looking through the drawings, for the purpose of this discussion, the necessity of care in selection has become very apparent. Many of the spots having full records of their behaviour in transit across the Sun's disc have been found untrustworthy witnesses, owing to the inconstant form of the umbra: the umbra may be spreading to one side, growing, or decaying, and the whole spot may be going through the process of division. A remarkable example of this kind of change is offered, as a warning, by a spot at about 20″ from the eastern limb on 1885 July 17. Its appearance then was very strongly in favour of Wilson's theory, and when near the central meridian on July 21 and 24 the umbra was quite sufficiently central to give any desired confirmation of the foreshortening effect at the limb. But on July 20, when the spot was at full 5′ from the limb, out of the reach of foreshortening, the penumbra was still dilated on the eastern side, and, comparing the drawings of the 21st and 20th, it was manifest that the umbra had extended eastwards to fill up the central void in the penumbra. If, therefore, this page of its history had been lost, the spot would have had great weight for the Wilsonian theory.

A similar example is the leading member of the twin spot on the drawings between 1888 May 11 and 23. This spot also went well for Wilson on the 12th, but failed afterwards. A new nucleus appeared on the 14th in the wider part of the penumbra, and the spot divided into a pair before arriving at the western limb.

Amongst the number of spots which tell against this supposed cavernous form there are not a few which go further and indicate rather a mountainous umbra, on the supposition of foreshortened effect upon the penumbra. The large round spot of 1887 June, selected by the late Father Perry to illustrate his paper in the *Memoirs* of the R.A.S. vol. xlix., is an instance of this. It was drawn on the 5th, when its centre was only 7″ of

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arc from the eastern limb, and the picture shows no penumbra on the off side, or limb side, while it is well in sight on the inward side, as if a dark elevation were screening the further side of the penumbra from view. The spot was regular, and there was nothing in its history to favour the supposition that its eastern side was wanting in penumbra at the time. Another example merits attention on account of an enlarged drawing made of it, after the usual chart of the Sun's surface was finished. On both the smaller and larger pictures only a thin trace of the penumbra is seen on the limb side, while it is well in sight on the opposite side, the spot being only 7″ from the limb. These drawings were made on 1889 July 12, and show the beginning of the second rotation of the great spot of the year which lived from June 16 to August 20.

A strong confirmation of Mr. Howlett's conclusion is offered by a large number of the Stonyhurst drawings which show spots very near to either of the solar limbs. The argument is suggested by Wilson's reply to De la Lande already mentioned. He there extends his computations to fixing the narrower limits within which the nucleus must be "hid" by the "lip of the excavation." These limits for his four cases of decreasing depths are 16″·9, 8″·9, 4″·7, and 2″·7. We have probably between 400 and 500 drawings of spots of every size and intensity within 10″ of either limb. Of these about one third would probably have to be rejected as too small to give any certain evidence; and all the rest, if we may trust the memory of the observers, would show Wilson's nucleus, or, as it is now called, the umbra, quite distinctly. It has not been thought necessary to re-examine the whole series of drawings for this argument, but as a test of the accuracy of memory those of the years 1884 and 1889, periods respectively of maximum and minimum frequency, were selected, and these provided, together, 64 spots within the 10″ limit: 24 of these were useless, and the remaining 40, at distances from the limb from 2″ to 10″, showed the umbra well marked and quite distinct from the penumbra. It is therefore safe to conclude that the umbra is not often shut out of sight by the "lip of the excavation."

The notches, seen occasionally in the Sun's limb when a spot has been rounding it, are extreme evidences of this nature; and Wilson evidently felt the force of De la Lande's attack, founded upon these dark indentations reported by De la Hire in 1703 and by Cassini in 1719. His answer is founded upon the belief that these were at least very small—so small that his shallowest spots might show the nucleus when at zero-distance from the limb. He would have found it impossible to answer the Dehra Dun photograph of 1884 September 17.* This admits of no other explanation than that of a high elevation of the umbra. He

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* A very faithful reproduction of this photograph is given in *Nature*, vol. xxxiii. p. 469.

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might have rejected its evidence as proving too much; and it must be admitted that if the photographic copy in our possession truly represents the border of the solar surface at the position of the spot, the phenomenon represented is of the rarest nature. We have nothing like it from the many observers of more recent times, including the hundreds of spots which must have been observed by Mr. Howlett very near to the limb. If such a piling up of opaque matter were not rare in the extreme, it would have manifested itself by an East-to-West widening of the umbra at some of these many observed positions near the limb. There is no such widening shown on the drawings of this spot when it was approaching the western limb; the umbra had diminished in apparent East-to-West width by one half between the 15th and 16th of September, and should have contracted to a mere line on the 17th. The Stonyhurst drawing on the 17th was made at four o'clock in the afternoon, probably about ten hours after the Indian photograph, and may have been too late to catch the umbra on the limb; only the penumbra is shown on the sketch. The Greenwich photograph was taken at 10^h 20^m A.M. of the same civil day—about four hours after the Indian photograph, and only the penumbra is quoted in the Greenwich volume as visible on the photograph. On the other hand, there is nothing on the Indian plate to indicate photographic treachery: the notching umbra is perfectly natural, of a strong silver deposit, and showing a woolly outline in every way like that of its neighbouring spot; and although we have nothing to compare with it in our collection of drawings, there are imitations of it on a microscopical scale in the form of a little notch in the outer penumbra in spots near, but not on, the limb. These have been also observed by Mr. W. Hale White, who describes them in the *Journal* of the British Astronomical Association, vol. v., No. 4, as "constantly noticed. When a spot was close to the edge, the umbra rose in front of the outer penumbra like a projecting rock against the sky." It is impossible, therefore, to reject altogether the evidence of the Indian photograph, and it goes straight for a mountainous rather than a cavernous form. Mr. Howlett has already stated the inadmissible postulates required for a physically hollow notch: it would mean a deep furrow lying East-to-West, of so great a length that it could not have failed to manifest itself on the previous day.

Mr. Howlett has expressed a conviction that the penumbra of a spot "presents a convex surface—a curve conformable to the general contour of the solar orb"; and, presumably, he includes the umbra in the curved surface. Our own observations at Stonyhurst, while confirming this statement as that of the usual form of a spot, lead to the admission of not unfrequent exceptions. It has been noted that some of the selected spots, which have been followed from limb to limb, score oppositely: at one limb for the Wilsonian doctrine, at another against it; and, again, that, in several of the cases quoted against

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Wilson, their opposition to his theory is more than contradictory of it: it is contrary to it, showing the wrong side of the penumbra contracted. Both these notes indicate elevation of the umbra rather than depression. It is a simple supposition, for bringing all the observations into accord, that the umbra, generally, is on a level with the penumbra, but sometimes above it, sometimes below. And it will probably be granted that this variation is more in keeping with the modern belief in some form of cloud-like opacity for the cause of the central darkness of a spot. The warmest supporter of the Wilsonion theory will hardly accept the physical part of it, that the darkness is the floor of a cavern opening to an opaque central mass; and without this prepossession on the part of Dr. Wilson it is not easy to see why he should have been at such pains to maintain that even shallow spots are but rare exceptions to a rule.

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An Apparatus for Mechanically Calculating Star Corrections.

By W. E. Cooke.

(*Communicated by Professor H. H. Turner.*)

This machine, the principal part of which is shown in plan in the accompanying diagram (see plate 5), is mounted on a deal table with a cover, the top of which can be used as a drawing-board.

It consists essentially of a square sheet of zinc, divided into two portions, A and B, by means of a circular cut. B is fixed securely to the table top, and A is pivoted at O, a substantial spindle ($\frac{3}{8}$ inch thick) being screwed to the table, passing through a metal sheath in A, and projecting slightly above it. A flat metal straightedge, or ruler, 28 inches long, having a small metal projection near one end, through which a $\frac{3}{8}$-inch circular hole is drilled, with its centre exactly in line with the edge of the ruler, is pivoted on that portion of the spindle which projects above A. On the under side of A, at the point marked C, clamping and tangent screws are fixed, passing through a slotted aperture of 20° in the table top.

Thus both A and the ruler can be turned, independently of each other, on the spindle O, and A can be clamped in any desired position.

On A the quadrant ODE is drawn. Each line or radius OD and OE is divided into tenths of an inch, and perpendiculars drawn through each point, thus reticulating the quadrant into 0·1 inch squares. Every tenth division is marked by a thick black line, corresponding to each second of arc. (These only are shown in the accompanying diagram figured 0 to 25, commencing from the centre 0.) The half seconds, or every alternate fifth division, are drawn in red, and a thin black line marks the intermediate divisions, or tenths of seconds. The ruler, pivoted at 0, is similarly divided 0–25.

The edge of the quadrant is divided into degrees, and every tenth minute of arc, starting at E, and every minute can be easily estimated. The rim of B is graduated into hours and minutes, starting at H and extending for 7^h. The minutes are figured, but the hours are *not.*

For any given night's work we have a set of stars extending over 2 or 3 hours in R.A. Take any one of these hours, multiply by 15 to reduce to degrees, and add to G (from the *Nautical Almanac*). This gives $(G+\alpha)$ corresponding to some whole hour of α. Let us take a simple case first. Suppose this value of $(G+\alpha)$ is less than 90°. Turn A on its pivot until $(G+\alpha)$ on the rim of A corresponds with some (unfigured) whole hour on the rim of B and then clamp. Then with a pencil figure this par-